Report of the MDL Science Review Committee

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A. Introduction

The MDL Science Review Committee was convened to review the current science and technology applications produced by the Meteorological Development Laboratory (MDL) of the National Weather Service's Office of Science and Technology (NWS/OST) and to make recommendations on improvements that could be made in the science and technology aspects of their mission. We met at MDL for two-and-one-half days (11-13 March 2003), with the first two days spent gathering information about the varied activities in MDL, as well as information about the work environment and attitudes toward new ideas and approaches. We met with the MDL director, all of the Branch managers as well as many of the Branch staff in group and individual settings. This report represents a summary of the Review Committee's findings.

The report is organized as follows: Specific (brief) responses to a set of questions that were posed by OST management are presented in Section B; these comments are very similar to the comments that the review committee presented to Jack Hayes (OST director) on the final day of the review, and are followed by a set of major recommendations. Section C contains a discussion of MDL activities, including MDL's historical context, followed by consideration of some general issues. Concluding remarks are presented in Section D. A list of specific comments, issues, and questions that were gleaned from observations during the review, and which may be of interest for OST/MDL management, are presented in Appendix C.

B. Responses to specific questions

A list of eight general questions was provided to the Review Committee prior to the review. These questions were used to guide the review and to anchor the discussions in this report. The original questions are listed in Appendix A.

Preamble:

Before responding to the specific questions that were posed, we feel it is important to highlight a major conclusion of our review. Much of MDL's strength is a result of the leading role that the lab has played in the development of statistical forecasting techniques over the past 35 or more years. In particular, the committee believes that

- *MDL is well positioned to make major contributions to the improvement of public and other weather forecasts through the development and implementation of new products and probabilistic guidance through*
    - Development of gridded Model Output Statistics (MOS);
    - Interpretation of ensemble forecasts;
    - Use of new datasets;
    - Development of advanced decision assistance tools;
    - Implementation of new advances in coastal and inland flood and wave modeling;

- *This capability should be viewed as an opportunity for MDL and OST/NWS to continue to be a global leader in statistical forecasting and forecast applications.*

Question 1: Overall, is the MDL's mission, vision, and science agenda optimally structured to meet the Science and Technology (S&T) needs of the NWS?

The Committee believes that the general answer to this question is "No." In particular, numerous issues related to professional development, alignment with other laboratories and centers in NOAA and the NWS, infusion of new ideas, and adoption of new scientific advances and technology have prevented optimal use of the capabilities of MDL and development of products needed for future NWS requirements. More information and details regarding these issues are included in later sections of this report.

Question 2: How well is MDL positioned to meet future NWS science and technology needs?

In some respects, MDL is very well positioned to meet future needs. In particular, MDL has a strong historical basis in the development of forecast guidance tools. This longevity and historical experience have resulted in an extraordinary knowledge base and

capabilities in certain areas. In fact, *MDL may possess the greatest expertise in the area of statistical interpretation of forecasts of any laboratory in the world*. In addition, the lab has access to a very large historical database that can be exploited for many new investigations and applications and the testing of new technologies.

In other respects, MDL is not as well prepared as it might be. As model output and observational datasets become increasingly large and complex, the need for guidance becomes even greater. However, at the same time, development of the guidance becomes more difficult with this increase in information availability and as the forecasters' jobs become more complex. Thus, *there is a great need for injection of new knowledge and expertise in MDL* to make this job possible.

Question 3: Are MDL programs optimally aligned? (e.g., best use of available funds)

It is the opinion of the Review Committee that MDL programs should be aligned to provide the most advanced, reliable and cost-effective guidance to the operational forecast community. In some Branches and situations this will require minor modification if any while in others, major adjustments are recommended. General and specific recommendations follow.

Questions 4-6: New science alternatives that should be considered in MDL programs

Questions 4-6 concern new scientific approaches that should be considered by MDL. Because they all require a similar response, we combined these questions.

A variety of alternative statistical approaches are available that should be considered, at least in an exploratory way, as approaches to improve guidance for forecasters and to provide enhanced decision tools. In addition, greater use of ensemble forecasts, development of a gridded MOS, and use of new data types could lead to significant improvements in guidance. Finally, incorporation of new storm surge, flood inundation and wave modeling technologies into operational storm surge-forecasting processes, both deterministic and statistical, could lead to enhanced capabilities in real-time coastal flood forecasting guidance.

Some of the available approaches are new, but others are commonly used in other areas of forecasting or statistical analysis, or have been applied experimentally. Some examples of alternative statistical approaches include (i) neural networks; (ii) General Additive Models; (iii)

Dynamic MOS; (iv) Bayesian approaches; (v) use of principal components analysis to reduce the dimensionality of predictor sets; and (vi) temporal-spatial models. Use of ensembles would enable MDL to provide much improved measures of uncertainty for a wide variety of variables. Appropriate ensemble approaches might include use of multi-models or super-ensemble approaches *with statistical interpretation.* Development of gridded MOS products would enable optimal use of the high-resolution model output that is becoming available and would provide more appropriate guidance to forecasters in the era of the Integrated Forecast Production System (IFPS). Use of new data types – especially remotely sensed databases – would enable development of observation-based very-short-term guidance for aviation traffic flow management and other applications. Storm surge, flood inundation and wave modeling capabilities have advanced tremendously over the past decade and could provide much greater information than the capabilities currently applied in MDL.

Question 7: Given the mission and capability of… are there suggestions for improving collaboration between MDL, FSL, and NSSL to improve science infusion?

The Review Committee concluded that *better collaboration is needed with the Forecast Systems Laboratory (FSL).* It appears that in the past there have been numerous problems associated with overlap and lack of coordination between the two laboratories. Some of these issues are considered in greater detail later in this document.

With regard to the National Severe Storms Laboratory (NSSL), we were not made aware of any ongoing collaboration between these two laboratories. However, it seems that *there are a number of ways that MDL and NSSL could benefit from working together in the future, which would aid the development of improved severe weather forecasts and warnings*.

In addition to the two laboratories mentioned above, we feel *it would be particularly valuable to create a team consisting of individuals from MDL and the Environmental Modeling Center (EMC) to work together on maximizing the information content of ensemble model output.*

Question 8: Are there suggestions for improving our leveraging of the external research community in the science infusion process through MDL?

A number of possible approaches should be pursued to enhance leveraging of the external research community and its knowledge. These approaches include *(i) offering MDL staff professional development through conferences, as well as visits to NCAR and other laboratories and universities, particularly those that have collocated Weather Forecast Offices (WFOs) and especially those with Collaborative Science, Technology and Applied Research programs (CSTAR); (ii) more aggressively pursuing opportunities and interactions with research entities that have common interests (e.g., Meteorological Service of Canada; research organizations); and (iii) taking advantage of advances from the external research community, such as storm surge, flood inundation and wave modeling.*

Professional development activities have at least a two-fold benefit: (i) they allow MDL staff to learn about new approaches and technologies which can be considered for infusion into new and current MDL products; and (ii) they facilitate formation of contacts with researchers and developers outside the laboratory, which may stimulate mutually beneficial collaborations. Other entities – in the U.S., Canada, and Europe as well as other locations – are faced with similar issues associated with large and complex datasets, and they are pursuing similar goals as MDL; collaboration with these entities also could be mutually beneficial.

Scientific and technological advances that have been made via the external research community, either independently of or in concert with other NOAA offices and programs should be adopted, as appropriate and necessary, to improve and expand MDL's capabilities and capacity. The not invented here syndrome must be abandoned if MDL is to take advantage of the many advances that have and are being made. In some cases, the science and technology transfer may be effected via the transfer of a CD or via a workshop hosted by NOAA while in other cases, institutional partnering may be required. In any case, MDL must be proactive and seek these leveraging opportunities. Here, knowledge of the peer-reviewed literature is beneficial.

Major recommendations

These recommendations represent overarching views of the Review Committee. This list includes some recommendations associated with the eight specific questions that were posed, as well as some recommendations that focus on other issues that were of concern to the Committee. However, it is important to recognize that recommendations concerning the work environment are also relevant to making the best use of MDL's scientific expertise and improving MDL's science and technology capabilities. Many of these recommendations are explored in greater detail in subsequent sections; they are presented here as a summary. Also note that these recommendations are not presented in any kind of priority order.

(1) ***Development of requirements:*** The process for setting MDL requirements is somewhat unclear and does not seem to be applied systematically or uniformly. A clear process – that is not too cumbersome – should be implemented and made clear to MDL managers and developers. More frequent and direct contact with users (e.g., WFOs) also would be beneficial.

(2) ***Reduction of support/maintenance activities:*** MDL staff members spend a significant amount of their time providing support for operational products and "turning the crank" to produce products that have the same "flavor" as old products (but perhaps involve different locations or new models). This overhead and repetitive work limits the amount of effort that MDL staff can devote to development of new products or improvement of

existing products. Product maintenance also provides a disincentive to new development, since each new product will require further support. The support function should either be fully funded within MDL, separately from the development activity, or the support function should be moved to another NWS entity.

(3) ***Near-term science and technology infusions***: MDL development efforts could reap rewards in the near future through several feasible activities: (i) bringing in the RUC model output for application in short-term MOS and LAMP forecasting efforts; (ii) development of a gridded version of MOS; (iii) development of ensemble-based probabilistic forecasts; (iv) implementation of existing enhanced storm surge, flood inundation and wave prediction models; and (v) assessment of new operational forecast tools created via independent NOAA programs such as CSTAR .

(4) ***New scientific/technological solutions*** MDL should consider, at least in a testing mode, newer statistical forecasting technologies such as General Additive Models (GAM), dynamic MOS, neural networks, and so on, which may have advantages over the regression approach for some variables and locations.

(5) ***Professional development:*** Opportunities for professional development are critical for retention of talented scientific staff, and to attract new staff. MDL will be better able to inject new scientific knowledge into its development of new products if MDL staff members interact on a regular basis with other researchers who are developing those technologies. MDL staff also should be offered time to explore new ideas as part of their jobs. This would include travel to major conferences.

(6) ***Development of personnel resources:.*** In order to develop new products and to investigate new science and technology applications, MDL staff needs to be re-invigorated with new PhD-level (or strong MS-level) scientists with expertise in forecasting, statistics, ensemble model interpretation, storm-surge forecasting, or other relevant areas. These positions should be made attractive, so as to appeal to the best talent, by offering challenges, freedom and opportunities to these young scientists.

(7) ***Collaborations with other laboratories:*** It appears that interactions between FSL and MDL are strained and collaborations between the two laboratories are not functioning optimally. An effort should be made to improve this relationship, perhaps with more staff exchange programs such as the one implemented by one of the MDL branches. In addition, increased collaborations with other NOAA laboratories and centers would be beneficial. For example, collaborations with NSSL would provide MDL with valuable knowledge and experience regarding approaches for severe weather forecasting. A team effort with EMC on applications of ensemble model output should also be productive.

(8) ***Collaborations with WFO forecast staff at offices collocated on university campuses:*** Interactions between MDL staff, WFO staff, and University faculty on campuses where a conscious decision was made to bring forecasters and researchers together in a setting

that is conducive to moving from need to discovery to testing to implementation should be encouraged. Some of these advances may have national implications.

C. Discussion

a. Context

It is the Review Committee's understanding that MDL exists primarily to provide operational guidance to NWS forecasters, and that the principal components of MDL's mission and effort are directed toward product development, maintenance, and forecast verification. MDL projects are mostly driven by NWS operational requirements and needs; however, MDL does have freedom to pursue ideas and to initiate projects in keeping with its mission.

Most of MDL's efforts focus on providing guidance for synoptic-scale weather prediction, aviation operations, and coastal storm-surge, flooding, and wave predictions. Products in support of these areas span time periods ranging from minutes out to seven days. It is of note that MDL, given its mission, has implicitly broadened the use of the word "meteorological" to include not only traditional atmospheric weather but also coastal ocean and lake weather events as well.

In order to perform a meaningful review of MDL it is helpful to briefly consider relevant historical background of MDL in the context of weather forecasting as well as the current and expected technological capabilities and partnership opportunities that are and will be affecting how modern and next generation forecasting may be done.

Much of the ground-breaking early work of MDL (known as the Techniques Development Lab, TDL) was completed in the 1970s. In particular, TDL was responsible for creating two products. One was called Model Output Statistics (MOS), statistical forecast guidance that is much better than raw model output and is so easy to use that it has become indispensable to operational forecasters everywhere. The second was the Sea, Lake and Overland Surges from Hurricanes (SLOSH) and as a consequence, the Maximum Envelope of Water (MEOW) maps, at the time, an advance in guidance tools.

SLOSH MEOW maps became very useful to forecasters in the late 1970s through the 1980s because the product provided guidance based on worst-case scenarios of Tropical Cyclones of a certain category making land-fall at a specific location. Given that there was no other guidance, that a numerical model was not being run in real-time in advance of an event and the somewhat poorer storm track predictions back then, the SLOSH model output guidance was very helpful. Also, the periods of the 1970's and 1980's were relatively quiet in terms of numbers of land-falling tropical cyclones so forecast accuracy pressures were not great. However this situation changed in the 1990's when more tropical cyclone events made landfall along the

U.S. eastern and Gulf coasts. Increased frequency of occurrence coupled with the tremendous growth in coastal populations, both permanent and vacationing, and even greater rates of increase in coastal housing and wealth, led to the need for more timely and accurate numerical model forecasts of coastal storm surge, flooding, inundation and wave fields. However, MDL did not choose to adopt new approaches to surge forecasting. Rather, it retained its existing model output maps. Only in the recent past has the Hurricane Research Division of the National Hurricane Center chosen to run the SLOSH surge model in real time for Tropical Cyclones and now Extra-Tropical Cyclones as well. But the existing model is seriously limited in fluid physics and thus its applicability is extremely limited. Meanwhile the capabilities of the academic community have moved far out in front of MDL.

Existing storm surge and coastal flooding modeling capabilities developed in the academic community should be evaluated and the feasibility of transferring the technologies to NOAA should be studied. Here, given the uncertainty of storm tracks and intensities, and the multiple storm model outputs being produced by NCEP and others, a MOS approach could be introduced as well. This would give MDL an important role to play in producing MOS for a "next generation" SLOSH; a MOS of NEXT-SLOSH. It should be pointed out that the existing SLOSH model is based on simplified physical processes describing depth-averaged water flow in coastal and estuary systems and developed using technology of the early 1970s. While SLOSH has worked well in some cases, the intrinsic limitations in its' model physics and numerics highlight the model shortcomings, which reduce the value of the guidance provided to forecasters.

On the atmospheric side, consider that in some instances wherein weather information is most critical, there can be large differences in conditions *within* an individual zone. For example, in the recent record-breaking snowstorm in Colorado, some snowfall amounts varied from a few inches to over four feet *within the same zone* (see Table 1 and Fig. 1). Similar examples can be given for wind speed, visibility, ceiling, etc. Moreover, the conditions within a given zone frequently change rapidly with time. Even if a forecaster knew exactly what was going to happen, it is not humanly possible to convey to all users for all points in all zones how a single weather parameter will evolve let alone the evolution of many different parameters. Likewise, it is not humanly possible to convey (quantitatively) the evolving *uncertainty* of each of the parameters of interest to varied users? Yet, with today's technology, it is possible to provide such detailed weather guidance in a forecast paradigm that is structured via a *user-interrogation* approach. User interrogation requires a four-dimensional (space and time) gridded array of weather information with a user-friendly menu and appropriate display software so that each user can seek and display weather information of their choice. Fortunately, the concept of a continuously updating high-resolution gridded array of weather information fits well with MDL capabilities and interests as a result of their important role in the National Digital Forecast Database (NDFD).

b. General issues

Most of the following comments are directly related to the questions (listed in Appendix A and discussed in Section B) posed to the Review Committee. Some items, however, are listed simply as topics or points of information that spontaneously arose during the review and may or may not be of value to NOAA management. The topics that follow are not listed in priority order.

(1) Intellectual freedom and productivity. For any professional science based institution to remain relevant, it must implement a process to routinely identify, ingest, test and assess new technology and to receive feedback on the utility of new products. MDL's staff consists of relatively few PhDs, mostly Bachelor's and Master's degree levels. The justification for this particular educational makeup of the staff is reported to be that MDL does not conduct basic research but rather, maintains and updates a suite of operational MOS products and writes code for new products. Still some MDL personnel feel that there should be more opportunity to capitalize on ideas conceived both externally and within MDL and to provide adequate feedback on the properties and performance of new products.

In regard to introducing new ideas and approaches, some personnel feel restricted/limited in their efforts and that management appears to be resistant to change. Resources should be provided so that innovations can be worked into the MOS and SLOSH frameworks (e.g., testing new mathematical formulations, neural nets, remotely-sensed data, MOS in IFPS, ensemble MOS, 3-D, non-linear, interactively coupled SLOSH, etc.) yet such efforts are not encouraged. Furthermore, it does not help when management believes that it usually isn't worth the effort to pursue new initiatives. It would be helpful if a sense of MDL vision, opportunities, initiatives, etc. were much more aggressively promoted within the lab.

There is also an intellectual capital issue. Where are the upcoming young PhDs, the solid idea folks who could get excited about and lead new projects? Management should pursue a healthy mix of new young talent. Perhaps the mission of MDL should be modified slightly to permit a more flexible development process that encourages ideas and creative thinking for new and better products. It is evident that creative productivity has been particularly lacking for a lab the size of MDL. In particular, Table 2 provides an unofficial breakdown of the MDL publications since 1997. Based on the refereed publications, it is clear that either very little that is new (a requirement for journal publication) has been done, or no priority has been given to publishing meaningful new ideas and results.

In summary, the following actions are recommended:

a) Hire new PhD scientists (or highly competent MS-level statisticians) to lead new efforts. The job description needs to be professionally appealing. MDL needs to be the repository of statistical forecasting expertise in the country.
b) Staff should be encouraged to propose new ideas and to spend some of their time developing them. Allow failure.

c) All staff should be given professional development or training opportunities
d) All staff should be able to participate in one or two conferences or workshops every year. Direct interaction with peers is very stimulating.
e) Staff should be encouraged to participate in the publication of their work.
f) Appropriate staff should work closely with peers doing related work in other places. One obvious example is to work directly with EMC/NCEP on developing new statistical forecast products, especially from ensembles.
g) Improve working relationships with the scientific community. This would involve more frequent exchanges and joint projects with the NOAA laboratories and the larger academic community.
h) Foster an environment where creativity and open dialog are prized. This type of atmosphere, along with a continual dialogue with the academic community and MDL customers will be vital to keeping MDL's work focused in the right direction.

(2) Requirements and User Feedback. Essentially, MDL is driven by "requirements" that are mostly externally imposed (typically they come through the OST). Product feedback from NWS users comes, second hand, from the Office of Services (OCWWS). Apparently, OCWWS provides MDL with relatively little feedback from the NWS field office users of its products. Thus, MDL staff members feel isolated from many of the users of their products. They rarely hear from NWS forecasters and WFOs directly because everything is supposed to be filtered through the Office of Services. In fact, most of the feedback they do receive comes from the private sector. While it is understandable that some type of filter for screening feedback may be appropriate, unless the individuals doing the screening are intimately familiar with both the needs of the NWS forecasters and MDL's limitations in modifying their products, it would seem that little meaningful interaction between the users and the product builders (MDL) can take place. It may be far more productive to have MDL scientists interact *directly* with the users in order to help them determine what, exactly, the users need, what are the deficiencies of present products, whether or not current products can be modified, or whether new ones, that better address forecasters' needs, can be created. For example, forecasters have noted that there is insufficient justification for retaining 3 or 6-hour, high-spatial-resolution details out to day 7 in the IFPS even though the software system requires them to do this. Management of MDL needs to recognize this *and other instances* wherein the software developers are driving the scientific products. Direct interaction of MDL programmers with the NWS forecasters would lead to corrections in such inappropriate policies and products. Clearly, improved communications are needed between MDL and the NWS policy, planning, and requirements organization.

(3) Machine resources. Not once did the committee hear complaints of inadequate computer resources. MDL depends upon internal PC and workstation as well as the NCEP computers and they seem to be able to handle all major projects and tasks. There are, however, a few items that would benefit the lab's efforts. In particular, access to the graphical capabilities available in certain commercial statistical programs would be

immensely helpful in examining system output. Upgrades in PCs and workstations would enhance productivity.

(4) Probabilistic guidance. What is holding back the switch to fully probabilistic guidance? For many years there has been strong resistance "from the field" – this resistance is partly the result of the requirements of the deterministic zone-forecasting paradigm. Therefore, even though many in MDL recognize the greater utility of probabilistic guidance, the zone forecasters want deterministic guidance so MDL has accommodated this by providing "best category" forecasts. Now, however, we see that major elements of the meteorological community are embracing the probabilistic guidance approach. The coastal flooding community would embrace this approach as well, were it exposed to the possibilities and opportunities. For example, the SPC has recently designed and built a system to provide fully probabilistic guidance for severe weather. At the recent USWRP Workshop on QPF, the overarching conclusion of the efforts of nearly 100 atmospheric scientists was to address QPF probabilistically, i.e., QPF guidance should be provided in categorical probabilistic form. Similarly, the recent NRC workshop on the future of aviation weather guidance also recommended that guidance should be provided in probabilistic form. Recently, at a WFO MIC workshop, the concept of probabilistic flood and inundation forecasts for all storms was presented and received an enthusiastic response. Clearly, this is an area wherein MDL can work closely with EMC to take full advantage of ensemble forecasting by statistically post-processing ensemble output and creating advanced probability distributions.

(5) IFPS. The Review Committee resonated with the critique of IFPS by Cliff Mass contained in the recent Feb, 2003 issue of *Weather and Forecasting*. These observations are partially confirmed by a summary of anonymous comments by NWS WFO forecasters about IFPS that were solicited as part of a student project (see Appendix B). However, many, especially younger forecasters, are adapting to the IFPS approach. MDL could assist with this adaptation and address some of the major issues mentioned by Mass by: (a) providing better first-guess fields to the forecasters using a high-resolution gridded MOS approach; this would be especially valuable at longer forecast projections where near-surface and sensible weather forecasts from models are terrible; (b) relaxing the requirements for high temporal and spatial resolution details at later forecast periods; (c) implementing ways to express uncertainty or probabilistic information into these forecasts; and (d) providing more training to forecasters on how to modify model guidance.

(6) Infusion of new technology. Numerous opportunities exist to infuse new technology and alternative statistical/mathematical approaches into MDL work. Opportunities to evaluate the benefits of these approaches could lead to improved guidance and decision tools. The use of ensembles clearly is an important approach to reach the capability to produce probabilistic guidance. However, new statistical approaches may also prove to be beneficial for enhancing the guidance and decision tools provided by MDL. Some of the technologies available that should be investigated (and which have proven beneficial for

statistical forecasting and development of decision tools in other organizations) include (a) various forms of nonlinear regression (including logistic regression, General Additive Models, CART); (b) dynamic or updateable MOS approaches (now under investigation at NCAR. MSC, and elsewhere); (c) fuzzy logic and other expert system approaches; (d) neural networks; and (e) use of principal components analysis to reduce the dimensionality of predictor sets. In addition, various efforts are underway in the academic community and national laboratories (including NCEP, UKMO, ECMWF) regarding the interpretation of ensemble model output as probability forecasts. Decision tools (e.g., for convective forecasting) are also under development at some U.S. laboratories, and these may be useful for NWS applications. Finally, the research community has already developed new storm surge, flood inundation and wave modeling capabilities that provide much greater information than the capabilities currently applied in MDL. While these new capabilities are already available in the academic and research communities, it will be necessary for MDL to evaluate, adapt and test their capabilities to meet MDL needs. Thus, MDL should become more open to considering these new approaches, and opportunities need to be created that allow MDL staff to investigate these approaches and conduct feasibility tests.

D. Concluding Remarks

For several decades, MDL has provided reliable and highly useful guidance to the entire operational meteorological community. It is no stretch to say that MDL is an absolutely critical cog in the NWS system. If their products were to suddenly cease, the timely provision of accurate weather guidance for the U.S. would slow to a crawl and, in some cases, grind to a complete halt. Moreover, MDL's statistical techniques add tremendous value to other NWS products, especially to NWP. To put this in perspective, it has been shown that the level of skill of the raw (not statistically post-processed) numerical model output is sometimes a decade or more behind the skill levels achieved as a result of the post-processing applied by MDL.

During the last ten years, MDL has maintained and/or increased its premier products with only marginal increases in its resources. For example, the number of MOS stations has increased substantially while the lab simultaneously added many more forecast options (such as new aviation products, thunderstorm guidance, and higher temporal resolution output). This was accomplished while the data types that MDL utilizes were doubling (from five to ten) and the amount of model output that it must process was increasing massively as spatial resolution increased, model output frequencies doubled, and new models were added. *MDL staff and management should be commended for these accomplishments*.

As NOAA goes forward, it is likely that still more types of observations will become available and that model output will continue to increase. Thus, the demand for statistically post-processed output from multi-model ensembles and guidance to utilize the new observations

assuredly will also increase. Yet, there is a danger developing, as much of the progress within MDL depends on just a few key individuals. Unless new talent is entrained relatively soon, the loss of these key people may severely hamper normal operations just when the development of new statistical techniques will be needed most. There is more need now than ever before for the special talents of MDL scientists, and the need is growing rapidly.

MDL could greatly improve the value of its services and products in flood and inundation and wave forecasting by taking advantage of the existing state of the science numerical modeling that exists in the academic community. The development of these new models was in some cases funded by MDL's parent agency NOAA, and MDL should capitalize on the agency investment. MDL should redefine its activity herein, partner with the appropriate organizations, test and adopt the models as applicable and appropriate and then move the model output into a probabilistic forecast using the success of MOS as the template.

Currently, MDL appears to be one of the most underutilized and under resourced NWS entities. Perhaps, over the years, upper-level management has misinterpreted MDL management's quiet resolve to perform well no matter what happens to their resources as an indication that no significant problems existed within the Lab. Like every other Lab, MDL has significant needs and they should be addressed. At present, it appears that MDL has too little say about its products and its own destiny. Of special note is that much more interaction should occur between MDL and EMC.

Finally, the Review Committee believes that there is no better organization in the world than MDL to create a diverse and comprehensive suite of fully probabilistic products. NOAA management needs to support MDL in shifting away from deterministic guidance and encourage MDL staff to design creative new ways of presenting guidance and output of decision tools in probabilistic form. The MDL staff is able and willing to take on this challenge[1]. In this era of electronic databases and the constant drumbeat about uncertainty and the need for probabilistic guidance, MDL could be and should be a shining star. Their plans for ensemble output post-processing (Figure 2) are right on target and should be strongly supported by management.

[1] As a side note, much of the credibility problem that the weather forecasting community has today stems from our insistence on providing deterministic guidance, even when we know at the start that the outcome of a given forecast is grossly in doubt. This deterministic approach is standard at most local media outlets and is taken to the extreme at some of the most well known national media sources. MDL has a tremendous opportunity to revolutionize the manner in which weather information is presented if it is able to create three-dimensional gridded arrays of categorical probabilities from which the media can create new graphical forms of guidance that convey the main thrust of a forecast while still readily depicting the uncertainty.

Table 1. Snowfall Amounts in Boulder County

Location	Amount (inches)
Lyons	2
Longmont	16
Erie	22
Boulder	23
Louisville	34
Eldorado Springs	38
Nederland	44
Eldora Ski Area	62
Jamestown	63
Allenspark	67

Table 2. Publications

Year	Refereed Journals*	Conference Preprints and Abstracts	Technical Procedures Bulletins and Office Notes	Conferences with one or more MDL papers
1997	1	10	10	5
1998	3	18	2	4
1999	2	5	0	5
2000	2	13	5	5
2001	0	7	7	4
2002	0	15	6	3
2003	1	3	2	2
total	9	71	32	28
manager 1	1	2	6	
manager 2		6	13	
manager 3	3	11		
manager 4	1	9		
manager 5		9		
manager 6	2		1	
*	Excludes a comment on a refereed paper			

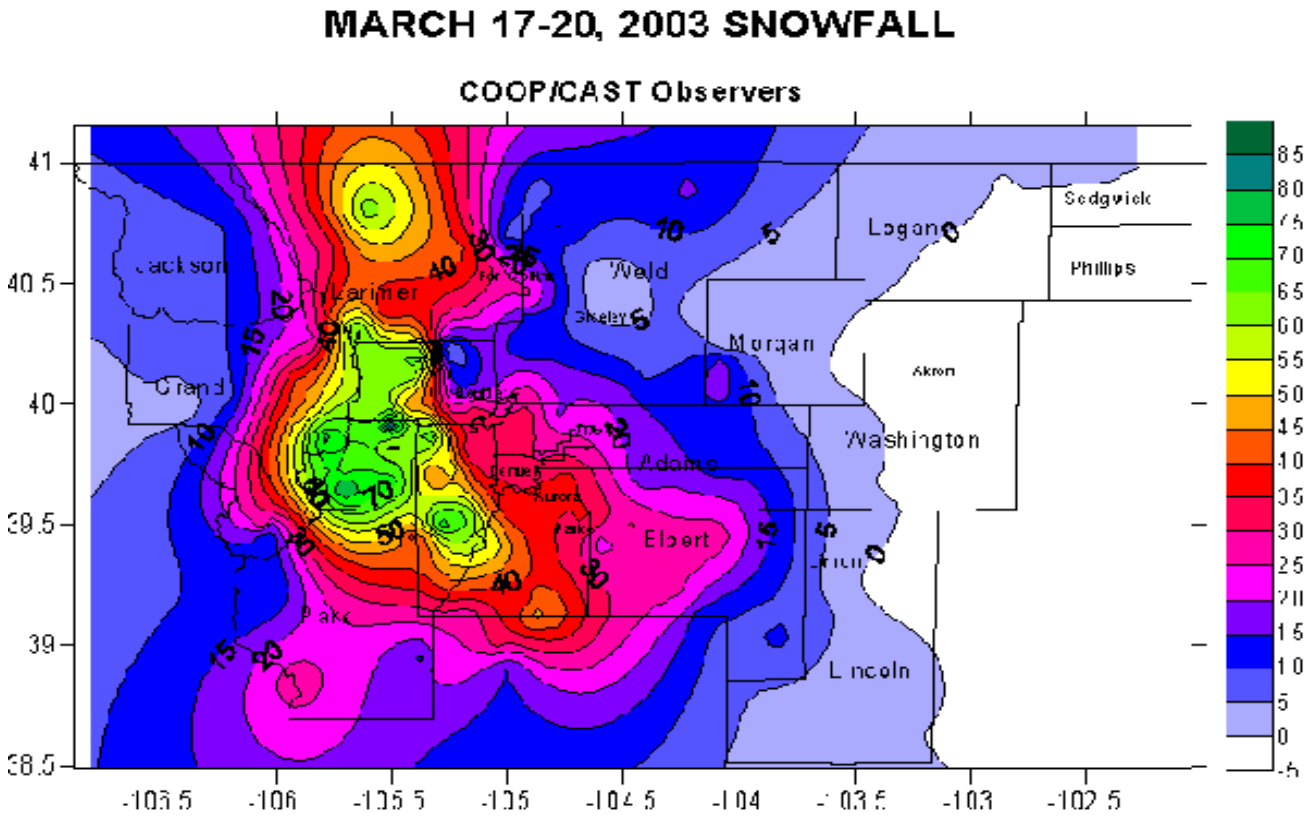

Figure 1. Central Colorado Snowfall (inches), 17-20 March, 2003. Analysis made available by the Denver, Colorado NWS WFO.

Ensemble Output Post -Processing Possibilities

Year	Statistical (1 Model Run)	Ensemble (Multiple Model Runs)
2002	NGM/Eta MOS AVN/MRF MOS Probability Guidance	Means/ Stand. Dev. Spaghetti Charts
2003	GFS/Eta MOS, Consensus MOS, Increased MOS Spatial Resolution	SREF MOS Evaluation of GFS Ensemble MOS
2004	High-Resolution Gridded MOS Prob. Enhanced MOS Prob. w/Ensemble Predictors	Cluster Statistics
2005	Fuzzy Logic MOS Post-Processing Stratification based on Predictability	Ensemble Probability Density Functions (Multiple Weather Elements)
2006	Non-Parametric Techniques, NDFD Prob.Info., Statistical Adjustment of Ensemble PDF's	
2007	Bayesian Processing w/ Enhanced Climatologies	

Figure 2

Appendix A: Review Questions

(1)Overall, is the MDL's mission, vision and science agenda optimally structured to meet the Science & Technology (S&T) needs of NWS?

(2)How well is MDL positioned to meet future NWS S&T needs?

(3)Are MDL programs optimally aligned?

(4)Are there science alternatives that should be considered in MDL programs?

(5)Are there S&T opportunities not being addressed by MDL?

(6)Are there new programs and science applications that MDL should consider to be better positioned to meet current and future NWS S&T Infusion needs?

(7)Given the mission and capability of NOAA/OAR's Forecast Systems Lab and National Severe Storms Forecast Lab, are there suggestions for improving collaboration between MDL, FSL and NSSL to improve science infusion-quality, speed and cost-effectiveness?

(8)Are there suggestions for improving leveraging of the external research community in the science infusion process through MDL?

Appendix B: Forecaster Comments on IFPS

From a Pennsylvania State University student-led survey of NWS forecasters.

1. "What do you like BEST about IFPS and why?"

- "Its potential. Once software is written so that a user on the Web can select any particular spot in an entire County Warning Area, and receive a "point forecast," that will give a big boost to meteorology and the NWS as a solid and important government agency."
- "It can produce a whole array of forecasts from the gridded data. Smart tools are real helpful."
- "Its versatility for product preparation"
- "You can actually "see" what you are forecasting, rather than trying to envision it while cranking out text."
- "I can't think of a thing."
- "The GFE and other bad part, the matrices are going away! The GFE allows the user to make a nice graphic representation of some weather elements."
- "the ability to convey greater forecast detail to the public"
- "You can generate many other products."
- "The IFPS database provides an element of continuity so that forecasters don't have to recreate the wheel when the official (going) forecast is still on target."
- "ISC is an easy way to see what's being forecast by other offices....mainly for the extended forecast. Short term coordination is done over the phone but no one ever coordinated long term before."
- "more detailed and flexible data source for users"
- "I have always had an areal picture in my mind of what I wanted to forecast, and IFPS allows me to paint (much of) that picture within the boundaries I am given. I also like that we can have different forecast output types (text/graphical products) fall out of an internally consistent database."
- "It produces a wide range of forecast products from a single database. Products will be consistent even though they are textual, graphical and tabular."

2. "What do you like LEAST about IFPS and why?"

- "The coding for SmartTools appears to be very hard to understand for me anyway. I'd love to compose some tools to cut down the large amount of time needed to make all those grid edits necessary to produce a good forecast. But at least at this stage, the programming seems complicated."
- "Cumbersome process of entering the numbers to many fields, some going out to 7 days. To help save time, I think the data should be sent from NCEP, already in a gridded format so

the forecaster does not have to create grids or create from scratch. All they would have to do is change the numbers in the grid. Handling a mixed precipitation event in IFPS is cumbersome."

- "The lack of a good method for collaboration with other sites"
- "There is still a some measure of intervention needed to produce accurate text forecasts, especially with complicated forecast packages. Also, all forecasters need to be in tandem by making the text output match the grids as closely as possible. One forecaster who ends up doing a lot of unnecessary text editing just passes more work onto the next guy. Also, there is more flip-flopping in the extended forecasts now compared to when we did text-only forecasts."
- "Hard to use, unreliable, poorly implimented, insufficient training, klunky-incomprehensible interface, poor support, inability to recover from failures"
- "The software is buggy and some times you lose all your work. The forecasts are specific and deterministic. We need more probabalistic forecast outputs and uncertainty, current forecasts portray too much exactness. The knobology hurts the meteorology."
- "editing grids very time consuming, and makes it hard to remain operationally aware of ongoing weather and make necessary updates."
- "One can spend a lot of time on graphics, taking away time from the charts. Also if one makes a mistake, one may not notice it, or it may take a lot of time to fix it."
- "Higher management's lack of understanding about its deficiencies, while at the same time cramming it down our throats."
- "Quick graphical updates in a changing event such as severe weather or multiple precip types are usually after the fact. Drawing pictures is much harder and takes a lot more time than a text update."
- "tedious, too much data out to 7 days"
- "The program itself seems to have more bugs than advantages. It has too many parts, and too many places for things to go wrong - and they do go wrong."
- "A few too many hoops to jump through. The software needs to be streamlined to get to product generation faster and allow us more time to forecast."

3. "What is the biggest obstacle, in your mind, to making IFPS everything it's intended to be? What is its biggest asset?"

- "The zone text formatter (i.e. the software that takes the gridded information and creates a zone text product from those grids) still has a lot to be desired. For every zone text that is created, one has to edit the product and make a number of changes. When the formatter is improved to the point where we no longer have to make changes, then that truly will be a great day indeed!"
- "Sometimes the wording is not quite right in the text of the zones. The gridded data and IFPS graphic products will serve the high end users, not the mom and pop radio stations who still rely on a text forecast."
- "Its a complicated program which is fully understood by only a few persons. Its best asset is that it works and provides a powerful tool for forecasting."

- "The biggest obstacle is the level of willingness (or unwillingness) of NWS forecasters to learn the software and utilize all its features. Its biggest asset is allowing forecasters to manipulate the models directly."
- "see above. People seem to like pictures. It appears to allow us to make cartoons and other pictures for the web."
- "Lack of a coherent and standarized training package. The IFPS software was a bigger paradigm change than the WSR-88D. We all got formal training on the latter. We developed our own on the former. HOws that for stupidity?"
- "It is a complex system. It has great potential.
- "LACK OF OPERATIONAL SUPPORT 24/7...AND A COMPELLING DISREGARD AND HESITANCY TO IMPLEMENT CHANGES REQUIRED BY THE FIELD TO MAKE THE PROGRAM EASIER TO IMPLEMENT AND USE. This has been going on for years, from the initial testing phase when some offices gave MDL a list of items that HAD to be corrected/fixed in order for that office to be able to use it for their CWA - and MDL would not make the needed changes in the software. As a result, the rest of the field received a software program loaded with problems and subject to data loss at a moment's notice."
- "Slow computers and unstable software."
- "HQ needs to realize that worded products are still important- IFPS cannot produce perfect wording for all situations. Asset is delivery of a lot of data for customers to use for their own particular needs."
- "The biggest obstacle seems to be the time it takes to make the database as detailed and as useful as can be. Time limits what the forecaster (even one that is relatively IFPS-savvy) can do. Deadlines must be met, and coordination must be done. I am not sure what the biggest asset of IFPS would be, but high on the (short) list of good things is that is makes it easy to keep a consistency from forecaster to forecaster, between the WFOs, and internally between individual products. Another good thing would be the ability to deliver this IFPS data to our more sophisticated customers/users in many different formats."
- "Getting the technology to the point that it makes IFPS viable. Meaning software good enough to quickly generate grids/forecasts and hardware capable of handling what is demanded and needed."

4. "Add any other relevant feelings or comments you have about IFPS, GFE, WWA, etc."

- **"**The concept of IFPS and what it can do is remarkable. The training on the IFPS program should have been a week away at a training center so the forecaster could master the technique. The technique in IFPS to generate proper wording in the zones forecast, such as "patchy dense fog", "cooler temperatures in outlying areas" need to be more user friendly. feels comfortable with the program."
- **"**As with all things, I hated it at first, but now it makes perfect sense. Fortunately, the programmers managed to work out most of the bugs BEFORE they shipped the software to the field."

- “WWA, overkill, similar comments to its design and useability to IFPS. We have moved into an era of making highly precise forecasts, when we should be focussing more on accuracy.”
- “It has been a long and painful transition from ICWF, the IFPS parent to IFPS and in the past 10 months, GFE has become the focus. It is a training and change management nightmare.”
- “We should really add more bodies to the field offices to really do a good job.”
- “Most people I know understand the importance of moving in this direction - it has been my feeling and continues to be that this may not be THE tool for us in the future. Sometimes I think scrapping it and starting over with updated programming techniques (C++, Java - NOT FORTRAN!!!!) is the way to go.”
- “With faster computers and better software and some practice we'll all get better at IFPS, but it's definitely more time intensive than typing text.”
- “Training, especially regarding best ways to actually produce products, was inadequate.”
- “Your first question (implementation) heads toward a rather significant point. The ideas behind WHY we (the NWS) were transitioning to use of IFPS for forecasts were NEVER clearly (or widely) stated by NWS management until well after the change was made and many growing pains had already occurred. An NWS-wide training program should have been underway well before use of the program to create forecast products was forced upon us. This may have helped many forecasters in understanding or at least anticipating the changes. Also, it sure would help if the programmers ever got the whole package of IFPS to work together without failures that have become common. Almost everyone has an IFPS crash story (or stories), about how they lost hours of work through no fault of their own.”
- “It will hopefully continue to improve. Many issues need to be resolved - training, coordination, product format... but the software is immensely improved over the initial release over 5 years ago.”

Appendix C: Specific observations, comments, issues, and questions

(1)The IFPS staff members (the code writers) feel that it is doing volunteer work to support IFPS. Evidently, portions of the code were created by FSL in a manner fundamentally different from the way that MDL would have structured the code, so it is difficult to address some of the problems. For over two years, phone calls have come to staff members at all hours of the night, sometimes several times a night. It has been so frustrating to the staff that about half of the original set of nine volunteers will no longer contribute their time to this activity thereby increasing the load further on the remaining cadre of volunteers. Although they feel that managers have acted, albeit slowly, on their behalf, the issue needs to be addressed by upper management as soon as possible. These support activities should be transferred to another NWS entity (e.g., the AWIPS support team).

(2)There is an issue regarding duplication of MDL efforts by FSL. FSL is viewed as the spin-up and spin-off lab but it apparently has made a decision to venture onto MDL's products turf much to the concern of MDL staff. Ideally, there should be a collaborative effort between MDL and FSL, given tight resources and no readily justified need for a duplication of effort. One of the MDL Branches has attempted to solve this problem by assigning an MDL staff member to work at FSL, with moderate success. However, this seems like a bandaid approach that requires more distributed personnel and would not necessarily work for the other branches that interact with FSL. This situation requires further attention from MDL management to arrive at a solution.

(3)LAMP has been under development for many years. Why is it still not fully operational? LAMP uses an "advective" model, which is fine for *very* short-term forecasts (e.g., an hour or two) but, because of vertical motion (i.e., propagation), LAMP has problems at longer projections. Can LAMP be converted fully to probabilistic form? We recommend that RUC forecasts be used for the "advective" component of LAMP, in place of the old advective models. Issues regarding RUC forecast and output timing and content can be worked out directly with FSL and NCEP.

(4)In addition to providing input to LAMP, RUC model output – if the RUC were run on a different schedule – would enable MDL to upgrade other short-term forecast products that are of particular importance to the aviation community. Office of Services should ensure coordination so that NCEP, FSL, MDL can optimize services for the FAA aviation community.

(5)The Storm Surge and Wave Prediction Branch did a great deal of original development work some three decades ago. However, other than their Hurricane Wave/Surge/Wind

Observations Proposal (with the Corps of Engineers, which itself is not at the forefront of this kind of modeling) and targeting Guam as a potential test site, they have fallen well behind the field in general and in their operational modeling services and products in particular.

(6)Inter-branch communication needs improvement. Interaction among the Branch Chiefs does not seem to be coordinated, so planning is splintered, and beneficial overlaps in the efforts of some of the branches are lost. Staff indicated an interest in knowing more about the work of the other branches so that collaborations, etc. could occur.

(7)MDL is working with a WFO Science and Operations Officer (Rich Grumm) to provide MOS ensemble forecasts. This is a good example of MDL's interaction with the forecasting community. More such interactions should be encouraged.

(8)MDL is using the COOP data to create new products. They also are using the MesoWest data (and are planning on using the RAWS data) to try to develop forecast equations for the high-terrain-impact West. This is precisely the type of development project that will have large and long term impacts on the quality and utility of the NDFD.

(9)MDL staff members anticipate providing many categorical probabilities in the NDFD. This should be encouraged.

(10)The process whereby MDL gets feedback from the field should be streamlined. MDL is not getting enough forecaster input through the current WSFO-OS-OST-MDL process.

(11)Before deciding on the statistical techniques of the future, small exploratory research initiatives should be initiated and evaluated. For example, neural net techniques could be tested in concert with a group that already has considerable expertise in this area, and provide it with "operational conditions" that make the tests provide results relevant to operational forecasting.

(12)The global and Short-Range Ensemble Forecast (SREF) ensembles (in combination with other models) are a gold mine for the development of probabilistic forecasts and other products. A team made up of MDL and EMC staff should work together to optimize the information extraction from these forecasts.

(13)NWS FOs should receive more feedback regarding how their forecasts are verifying.

(14)MDL staff are eager to work with new high-resolution data from satellites, radars and other new observing systems in order to improve their products. Efforts should be made to have these data available.

(15)Given the major changes recently imposed on how forecasters do their job, it seems logical that forecasters should be trained in how to modify NWP fields in the IFPS process,

much as the NWS supported training efforts for NEXRAD, AWIPS, etc., and given NWS support of COMET. (As noted in the recent article by Cliff Mass, the process of modifying fields is very difficult.) MDL could play a role in that training, especially if MOS is adopted to be the input fields to IFPS.

(16)MDL has traditionally had a strong student intern program that has been beneficial to both MDL and the students. We recommend that this program continue.

(17)MDL's Decision Assistance Branch (DAB) conducts customer surveys regarding its products. Other branches should consider doing this.

(18)The development of a "total" probabilistic forecasting approach in the NWS has to be viewed as the "way to go" by senior management, and given the same kind of priority as, say, the, quantitative precipitation forecasting (QPF) effort has received. MDL could lead this effort if it became part of the NWS Strategic Plan (assuming personnel – new talent – issues are addressed).

(19)MDL should take greater advantage of the severe storm and radar data expertise at NSSL.